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CR-72935

DEVELOPMENT TEST REPORT

AND

FINAL TECHNICAL REPORT

WESTINGHOUSE PART NO.

976J412-1

THERMAL LAG, HERMETICALLY SEALED ROTARY INVERTER

AEROJET GENERAL PURCHASE ORDER OP-101539

I. APPARATUS

Westinghouse Part Number 976J412-1 Rotary Inverter.

MAJOR CHARACTERISTICS

SYSTEM	Mode 1	Mode 2
Rated Output	370 watts	1700 watts
Voltage (line-line)	19 volts 37,5A	88 volts 39,8A
Power Factor (lagging)	0.30	0.28
Phase	3	3
Frequency	95 cps	220 cps
Speed	2850 RPM	6600 RPM
Rated Operating Time	5 hours	8-1/2 minutes
INPUT PARAMETERS	Mode 1	Mode 2
Armature voltage	27-33 volts	27-33 volts
Shunt Field Voltage	16 volts	2 volts
Shunt Field Current	3 amps max.	0.5 amps max.
Armature Current	24 amps	172 amps max.

II. APPLICATION

The inverter was designed to provide startup power for the Snap-8 nuclear power system per Aerojet General Specification AGC-10281A.

III. CONTRACT AND ORDER REFERENCE

Quantity	Aerojet General Purchase Order	Contract	Westinghouse General Order
2	OP-101539	NASA NAS5-417	LAD-25762

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SECTION I

SNAP-8 INVERTER DEVELOPMENT TEST REPORT

I. GENERAL TEST CONDITIONS AND PROCEDURE

A. Applicable Documents

Detailed test procedures are specified in Westinghouse T.L. F4435-C, Westinghouse Test Specs. 674141, Rev. A, 674142, Welding Spec. Dwg. 928A235 and X-Ray Spec. MTS 80382. These documents implement testing in compliance with Paragraphs 4.5 through 4.10 of AGC Spec. 10281A.

B. Test Conditions

1. Ambient Temperature: 25°C ± 10°C.
2. Altitude: Sea level.
3. Mounting: Shaft horizontal for tests 9, 10, 11, 12(b), 13, 15, 16. Shaft vertical for tests 2, 3, 4, 5, 12(a), 14.
4. Atmosphere: Inverter operated in air with blast cooling on the brushes for tests 9, 10, 11, 12(b), 13, 15, and 16. Inverter sealed and pressurized with 1 PSIG of helium and surrounded with a 12-inch layer of glass wool for tests 2, 3, 4, 5, 12(a).

C. Test Sequence

Tests 9 and 16 were run after magnetizing the rotor and load stabilizing to produce 19.4 volts line-line at rated load, 95 cps when operated in air. Other operational tests were run after magnetizing the rotor and assembling it into the inverter with no load stabilization.

II. ACCEPTANCE TESTS

1. Examination of Product

Reference: 1. Para. 4.10.1 of AGC Specification 10281A.
2. Westinghouse Inspection Records.

Apparatus Tested:

Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1

Test Procedure:

The inverter was weighed after assembly was completed. Compliance with applicable drawings with respect to material, dimensions, electrical connections, etc., was determined by a predetermined inspection sequence during fabrication of parts and assembly of the inverter.

Test Results:

Weight

S/N 2	318.5 lbs.

Examination

S/N 1 and S/N 2	Compliance with applicable drawings is recorded on Westinghouse inspection records.

2. Insulation Resistance Test

Reference:
1. Para. 4.10.2 of AGC Specification 10281A.
2. Westinghouse Acceptance Test Record Sheets.

Apparatus Tested:

Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

With the inverters hot from full load operation, a 500-volt, d-c test voltage was applied successively to specified pairs of terminals. Test voltage was maintained for one minute at each pair of terminals.

Test Results:

The insulation resistances of the various components of the inverters were as follows: (Values in megohms)

	S/N 1	S/N 2
Generator Terminal T12 - Inverter Housing	7000	1800
Motor Terminal A2F2 - Inverter Housing	6500	120
Generator Terminal T12 - Motor Terminal A2F2	100000	1500
Average Generator Winding Temperature (°C)	102	100
Average Motor Winding Temperature (°C)	112	116

Conclusions:

The insulation resistances from the generator and motor terminals to ground and between generator and motor terminals were well in excess of the required value of 1 megohm.

3. Dielectric Test

Reference: 1. Para. 4.10.3 of AGC Specification 10281A.
2. Westinghouse Test Record Sheet K1932889 and Acceptance Test Record Sheets.

Apparatus Tested:

Snap-8 Rotory Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

With the inverters warm from full load operation, test leads were applied successively to the specified pairs of terminals. Applied voltage was increased from 0 to the required value of test voltage at a rate not exceeding 500 volts per second. At the conclusion of the test the applied voltage was reduced at the same rate before test leads were removed.

Test Results:

a. S/N 1 and S/N 2

The generator windings sustained 1200 volts RMS, 60 CPS to the inverter housing for one minute without breakdown.

The generator and motor windings sustained 1200 volts RMS, 60 CPS between them for one minute without breakdown.

The generator windings sustained 1800 volts RMS, 60 CPS between phases without breakdown during manufacture before the neutral was connected.

b. S/N 1

The motor field and armature circuit sustained 400 volts RMS, 60 CPS to the inverter housing for one minute without breakdown.

c. S/N 2

The motor field and armature circuit sustained 1000 volts RMS, 60 CPS to the inverter housing for one minute without breakdown.

Conclusions:

Inverter S/N 1 met the dielectric requirements of the specification except with respect to the motor winding to ground circuit which exhibited an excessive value of leakage current at potentials greater than 400 volts.

It was suspected that the motor brush thermocouple lead was providing a high leakage path to the housing. The thermocouple lead of inverter S/N 2 was therefore sleeved.

Inverter S/N 2 met the specified dielectric requirements in all respects.

4. Line Voltage Balance

Reference:
1. Para. 4.10.4 of AGC Specification 10281A.
2. Westinghouse Acceptance Test Record Sheets.

Apparatus Tested:

Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

The inverters were operated at no load and at rated load at both 95 CPS and 220 CPS. Line voltages were recorded.

Test Results:

	% Unbalance	
No Load	S/N 1	S/N 2
95 cps	0.13	0.00
220 cps	0.00	0.00
*Full Load		
95 cps	0.15	0.14
220 cps	0.08	0.00

Conclusions:

The maximum line voltage unbalance is well within the specified 1.5 percent limit.

*Maximum unbalance during 5-hour full load operation at 95 CPS followed by 8.5 minutes full load operation at 220 CPS.

5. Full Load Operation

Reference: 1. Para. 4.10.5 of AGC Specification 10281A.
2. Westinghouse Acceptance Test Record Sheets.

Apparatus Tested:

Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

The inverters were operated at rated load, 95 cps for 5 hours followed by 8.5 minutes operation at rated load, 220 CPS. Motor armature voltage was maintained at 28 volts during the test. The inverters were pressurized with 1 PSIG of helium and surrounded with a 12-inch thick layer of glass-wool insulation. Input and output voltages and currents, output power, and thermocouple outputs were monitored throughout the test.

Test Results:

A tabulation of inverter input and output quantities measured at intervals throughout the 5-hour, 8.5 minute run is given on the reference Test Record Sheets.

Conclusions:

Specific areas of inverter performance are discussed more fully in sections of this report covering Voltage and Frequency Stability, Generator Overload Capabilities, and Generator Rotor Leakage Flux. In general:

1. Terminal voltages were outside the range specified. (S/N 1: -5.5% at 220 CPS, +7.0% at 95 CPS, S/N 2: +1% at 220 CPS, +10% at 95 CPS versus a specified tolerance of ± 2%.)
2. Efficiency at 95 CPS was satisfactory while efficiency at 220 CPS was significantly lower than specified.
3. Voltage drift during the operating cycle was satisfactory.
4. Maximum hot spot temperature during the operating cycle (188°C at the positive brush of S/N 2) was well below the specified maximum value (205°C).

6. Leakage

Reference: 1. Para. 4.10.6 of AGC Specification 10281A.
2. Westinghouse Acceptance Test Record Sheets.

Apparatus Tested:

Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

Leakage of selected components and of the complete inverters was measured by the mass spectrometer method in accordance with Westinghouse Test Spec. 674142.

Test Results:

Both inverters passed the test. Repair of terminals and thermocouple headers was required as specified in approved SDAR's before units would pass the leakage test.

Conclusions:

The inverters met the leakage requirement.

7. Dye-Penetrant Inspection

Reference: 1. Para. 4.10.7 of AGC Specification 10281A.
2. Westinghouse Test Record Sheets.

Apparatus Tested:

Welds on Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

All welds except electrical and thermocouple connections were dye penetrant inspected in accordance with Specification MIL-I-6866.

Test Results:

Approved SDAR's were required on one or two welds which did not meet the dye penetrant requirements.

Conclusions:

Further development of welding techniques and changes in weld joint design will be required to meet all AGC requirements. All welds on the two inverters met the helium leak test requirements.

8. Radiographic Inspection

Reference: 1. Para. 4.10.8 of AGC Specification 10281A.
2. Westinghouse Acceptance Test Record Sheets.

Apparatus Tested:

Welds on Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

All welds except electrical and thermocouple connections were subjected to radiographic inspection as required.

Test Results:

Several welds failed to pass the radiographic requirements. In these cases the X-Rays were forwarded to AGC for disposition. The welds were then either reworked or accepted by the SDAR Procedure as required. Final acceptance was based on passing the helium leak test.

Conclusions:

A program to improve welding techniques will be required if additional inverters are ordered. This program will include re-design of some weld joints, more weld samples to determine best joint designs, a review of fixturing and cleaning techniques and refinement of machine settings.

Most of the welding was done by the electron beam process. This process offers many advantages such as less dependence upon operator technique, minimum heat to ceramic terminals, minimum warpage and a non-oxidizing environment. On the other hand, it is a relatively new process which requires a certain amount of de-bugging.

III DEVELOPMENT TESTS

9. Critical Speeds

Reference: 1. Para. 4.10.9 of AGC Specification 10281A.
2. Westinghouse Test Record Sheet K1932869.

Apparatus Tested:

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure:

The inverter was operated slowly over the speed range from 2280 to 9300 RPM. Any unusual noise, excess vibration or other indication of malfunction was noted.

Test Results:

A critical speed was encountered at 9300 RPM. Specification requirement was no critical speed between 2280 and 9900 RPM.

Conclusions:

The 9300 RPM critical speed permits safe operation at the maximum rated speed of 6600 RPM. Special care must be taken to stay below the 9300 RPM critical in all testing.

10. Overspeed

Reference: 1. Para. 4.10.10 of AGC Specification 10281A.

Apparatus Tested

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure (required)

With the inverter initially operating at 220 CPS, the speed shall be slowly increased to 9900 RPM and held at that speed for 5 minutes.

Test Results:

The unit could not be operated to 9900 RPM without damage because of the 9300 RPM critical. The unit was operated to 9300 RPM during the critical speed test.

Conclusions:

The 9300 RPM speed to which the inverter was subjected in the Critical Speed Test will insure safe operation at the maximum rated speed of 6600 RPM.

11. Speed-Adjustment Test

Reference: 1. Para. 4.10.12 of AGC Specification 10281A.
2. Westinghouse Test Record Sheets K1932879 and K1932880.

Apparatus Tested:

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure:

With the inverter operating at an output frequency of 95 CPS at the beginning of the 5-hour full load run, the speed was varied to produce 85 CPS and then 105 CPS.

At the end of the full load operation with the output frequency initially at 220 cps, the speed was varied to produce 200 CPS and then 240 CPS. Measurements included the shunt field current and shunt field voltage drop.

Test Results:

Test measurements are shown on the referenced test record sheets.

Conclusions:

The inverter met the speed adjustment requirements.

12. (a) Voltage and Frequency Stability

Reference: 1. Para. 4.10.13 of AGC Specification 10281A.
2. Westinghouse Acceptance Test Record Sheets.

Apparatus Tested:

Snap-8 Rotary Inverters S/N 1, S/N 2, Part Number 976J412-1.

Test Procedure:

The inverters were operated at rated load, 95 CPS for a period of 5 hours followed immediately by 8.5 minutes of operation at rated load, 220 CPS.

Test Results:

	% Drift*	
	S/N 1	S/N 2
95 CPS	0.79	0.00
220 CPS	0.05	0.56

Conclusions:

Voltage drift during both modes of operation was well within the specified value of 2 percent.

$$\text{*\% Drift} = \frac{100 \times (\text{Maximum or Minimum Average Line Voltage During Run} - \text{Average Line Voltage at Start of Run})}{\text{Average Line Voltage at Start of Run}}$$

12. (b) Voltage and Frequency Deviation

Reference: 1. Para. 4.10.13 of AGC Specification 10281A.
2. Westinghouse Test Record Sheets K1932877, and K1932878.

Apparatus Tested:

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure:

The inverter was operated at rated 95 CPS load for a period of 5 hours followed immediately by 10 minutes of operation at rated 220 CPS load. Motor armature voltage was held at 33 volts for the first half-hour of operation, reduced to 28 volts for the next four hours and thirty-five minutes of operation, and set at 27 volts for the last five minutes of operation. The generator load bank was set up to produce rated 95 CPS load at 95 CPS and was allowed to vary with frequency during operation with 33 volts on the motor armature. Similarly the load bank was set to produce rated 220 CPS load and allowed to vary with frequency when the armature voltage was reduced to 27 volts. Field current was maintained at 115 percent of its 95 CPS value during high armature voltage operation and at 96 percent of its 220 CPS value during low armature voltage operation.

Test Results:

The 5 percent requirement of Para. 3.4.1 was exceeded as shown below and on the referenced test record sheets.

Arm Volts	Speed	Field Volts	Field Current	Shunt Field Temp (°F)	Load Watts	Output Volts	Output Current	% Speed Variation
28	2850	12.0	2.0	126	380	20.2	37.4	0
33	3330	13.4	2.3	134	455	23.75	37.6	+ 17
28	2850	12.1	2.0	154	385	20.2	37.4	0
28	6600	2.5	0.4	164	1690	85.2	39.7	0
27	6210	2.48	0.38	216	1525	80.2	39.4	- 6

Conclusions:

The original design calculations which were submitted to Aerojet showed the inverter would not meet the required 5 percent limits.

The speed and voltage regulation can be improved but only by adding weight and decreasing efficiency. A design with better regulation would require less magnetic saturation at the low speed and less armature distortion at the high speed.

The regulation will be somewhat better when the inverter output is driving a pump because the pump load changes faster with changing speed than does the load bank.

13. Commutation

Reference:
1. Para. 4.10.14 of AGC Specification 10281A.
2. Westinghouse Record Sheets K1932865, K1932866, K19322877 and K19322878.

Apparatus Tested:

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure:

Commutation was observed during the 5-hour full load operation at 95 CPS and during the 8.5 minute full load operation at 220 CPS.

Test Results:

No sparking could be observed during the full load testing. Commutation is shown as #1 on the Test Record Sheets. This is based on a Westinghouse rating system in which #1 is the best possible (black) commutation.

Conclusions:

Commutation was well within specification requirements.

14. Winding Resistances

Reference: 1. Westinghouse Test Letter F4435-C, Para. II-1.
2. Test Record Sheet: K1932888.

Apparatus Tested:

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure:

Generator winding resistances were measured at the inverter output terminals. The last three readings were taken with the contactor actuated. All measurements were made with a Kelvin Bridge.

Test Results:

Terminals	Resistance at 25°C
T11-T21	0.0178 ohms
T21-T31	0.0180 ohms
T31-T11	0.0177 ohms
T12-T22	0.0620 ohms
T22-T32	0.0618 ohms
T32-T12	0.0610 ohms

Conclusions:

Test values of low speed winding resistance were somewhat higher than the calculated value probably because of the severe cold working undergone by the stator coils during forming.

15. Motor Saturation Curve

Reference:
1. Westinghouse Test Letter F4435-C, Para. II-4.
2. Westinghouse Test Record Sheet K1932862.
3. Design calculations submitted to Aerojet on AGC P.O. OP-101539.

Apparatus Tested:

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure:

The inverter was driven at 3000 RPM by an external motor while the shunt field current was varied from 0.2 to 4.0 amps. The voltage generated in the motor armature with no current flowing in the armature circuit was measured and recorded for each value of shunt field current.

The voltage was converted to flux from the equation

$$N = \frac{1.5 \times 10^5 \times Ei}{T(\phi)} \qquad \text{where}$$

Ei = Measured Voltage
T = Turns per Coil of Armature
ϕ = Flux (kilolines)
N = Motor Speed (RPM)
1.5×10^5 = Calculated Constant for motor

The ampere turns per pair of poles was determined from the equation
$AT/PP_{SH} = I_{SH} \times T_{SH} \times 2$
where

I_{SH} = shunt field current

T_{SH} = shunt field turns per pole = 250

Test Results:

The test and calculated saturation curves are shown in Figure 1. The test curve shows slightly more flux than the calculated curve.

Conclusions:

The test saturation curve is a little bit better than the calculated curve.

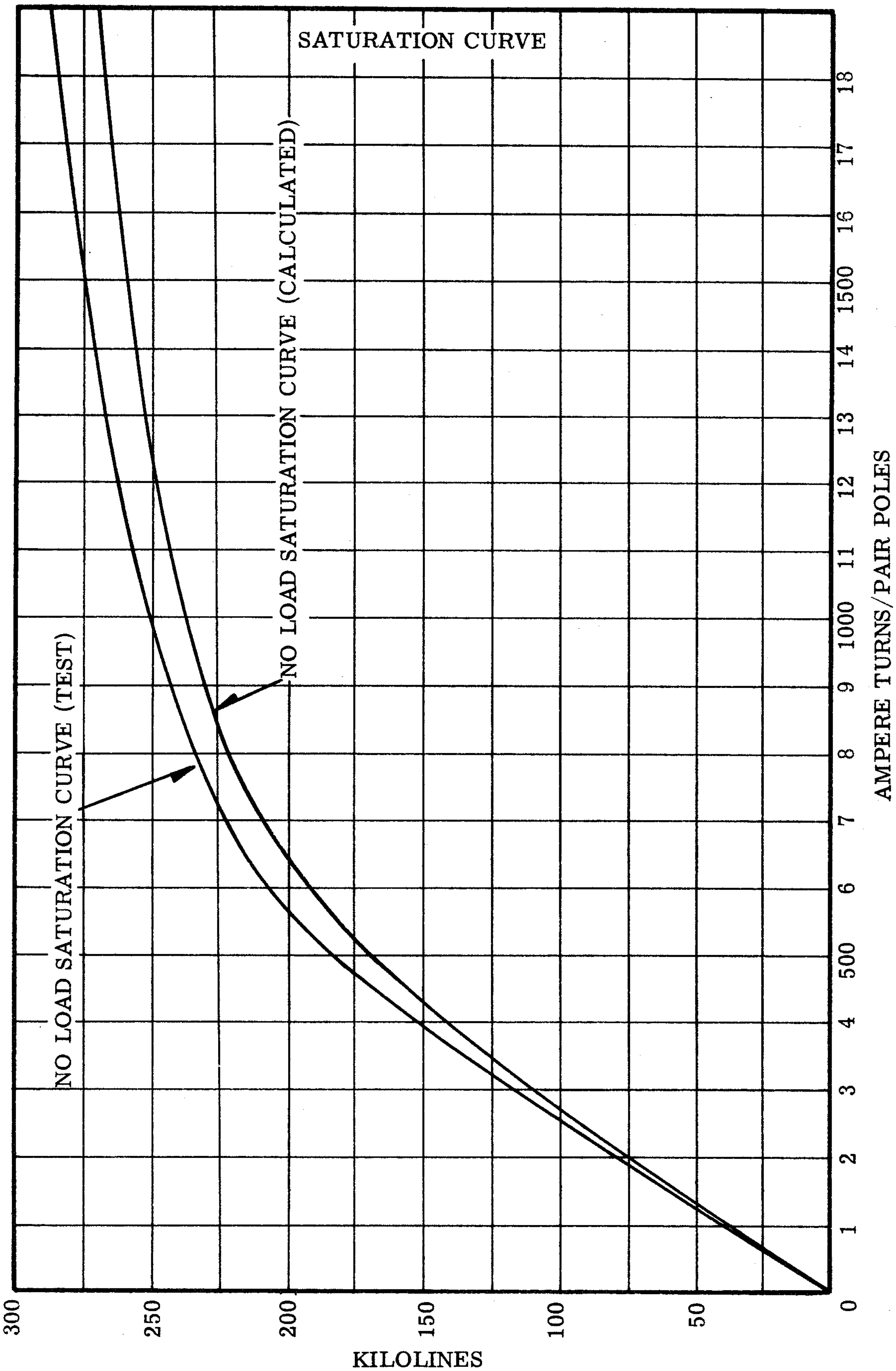
SATURATION CURVE
NO LOAD SATURATION CURVE (CALCULATED)
NO LOAD SATURATION CURVE (TEST)
AMPERE TURNS/PAIR POLES
0 1 2 3 4 500 6 7 8 9 1000 11 12 13 14 1500 16 17 18
KILOLINES
300 250 200 150 100 50 0

Figure 1

16. Generator Minor Hysteresis Loop

Reference:
1. Westinghouse Letter F4435-C, Para. II-4.
2. Test Record Sheets K1932863 and K1932864.

Apparatus Tested:

Snap-8 Rotary Inverter S/N 1, Part Number 976J412-1.

Test Procedure:

The inverter was operated at 2850 RPM at no load and at a load of 10 amps/phase at power factors ranging from unity to 0.10 lagging. Terminal voltages, line current, and output power were measured at each value of power factor.

Test Results:

From the test values of voltage, current, power factor, winding resistance, and the machine parameters, a curve of useful flux versus demagnetizing amp turns/pole was computed. This curve is compared with the predicted curve in Figure 2.

Conclusions:

Calculated and test values of minor hysteresis loops agree well over the range covered by this test. Refer to the section, Generator Rotor Leakage Flux, for a more detailed analysis of test and calculated hysteresis loops.

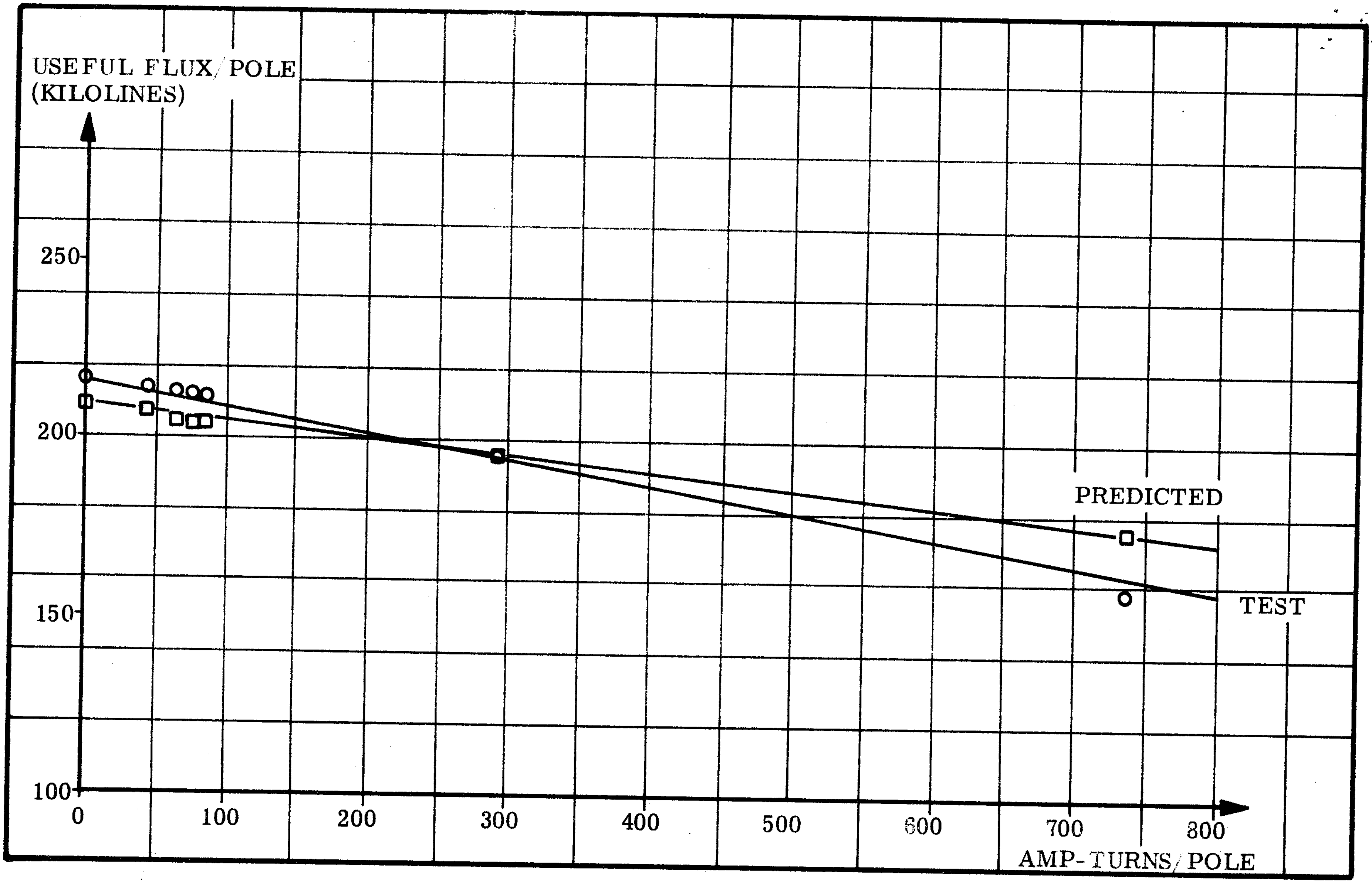

Figure 2. Test and Predicted Minor Hysteresis Loops Inverter S/N 1 (Ref. Test Record Sheets K1932863, K193264)

SECTION II

DISCUSSION OF GENERATOR CHARACTERISTICS

I. KEEPERING DURING ASSEMBLY

A. Methods of Stabilization

In general, permanent magnet generators may have their field strength adjusted after magnet charging by one of two methods - air stabilization or load stabilization.

Air stabilization is attractive for permanent magnet rotors in machines subject to frequent disassembly since it obviates the need to keeper the magnets when they are removed from the machine. However, since the permeance of the leakage paths seen by the rotor magnets during air stabilization is small compared to the permeance of the flux paths offered to the magnets when the rotor is assembled in the generator, the magnets undergo severe demagnetization. A large percentage of the available magnet flux is thus lost. To compensate for this lost flux, oversized magnets must be used and thus a weight and size penalty is incurred.

Load stabilization consists of either charging the magnets to saturation in their ultimate magnetic circuit (i.e., the generator stator) or charging the magnets in some external magnetic circuit and transferring them into the stator while maintaining them at full charge by means of a keeper. The field strength is then set by subjecting the magnets to the desired demagnetizing magnetomotive force (MMF) by loading the machine with the appropriate combination of current and power factor.

Since load stabilization subjects the magnets to only sufficient demagnetizing MMF to protect them from permanent flux loss at the most severe service condition (maximum load current and minimum power factor), a higher percentage of the magnet's potential flux output is available and thus, for a given machine, smaller magnets, mechanical structure, etc., can be used with load stabilization than with air stabilization.

B. Keepering

The function of the keeper is to provide the rotor magnets with paths whose total permeance is sufficient to maintain the magnets' operating point on the demagnetization curve at or above the load stabilization point during storage of the rotor after magnet charging and during assembly of the rotor into the generator.

The ideal keeper material should possess a high permeability and a high saturation level. Ingot iron was chosen for this application since its saturation level is higher than that of any commercially available material. (Vanadium permendur and electrolytic iron have saturation levels approximately 5 percent above that of ingot iron but their costs are prohibitively higher.)

The cross-sectional area of the keeper under the stator winding end extensions is limited by the clearance between the stator bore and the end extension I.D. To reduce the level of saturation in this portion of the keeper, an additional low permeance flux path is provided by placing an iron ring in contact with the motor end of the permanent magnet rotor during assembly of the rotor into the inverter. This ring facilitates passage of flux both between pole tips and between magnet ends of opposite polarity, thus reducing the flux that must be carried by the keeper.

Because of the many flux paths involved, an exact determination of the effect of the keeper on the rotor magnet operating point is not possible. A pessimistic analysis (All flux is assumed to travel through the tapered end of the keeper in an axial length of 3.2 inches and leakage flux is taken as equal to the calculated value.) indicates that the magnets would be stabilized to between 2 and 3 per unit (PU) load as a result of passing through the keeper. Calculations based on the test values of leakage show that keepering should hold the magnet operating point at or above 1 PU stabilization since test leakage exceeds calculated leakage. Test values of no load voltage taken immediately after assembly verify that the magnet operating point is indeed at or above 1 PU. Based on the test value of magnet leakage and magnets producing 98 percent of specified flux, voltage would be reduced 5 to 10 percent if the rotor were transferred from the magnetizing fixture to the inverter with improper or no keepering.

II. MAGNET STRENGTH

A. Criteria for Magnet Selection

In general, three magnetic properties are significant in permanent magnet generator design - residual flux, coercive force, and recoil permeability. Because of the low power factors, high currents, and efficiency requirements of this application, it is desirable that a material possessing a combination of high residual flux, high coercive force, and low recoil permeability be used. The material should produce sufficiently high residual flux that the number of series turns in the winding can be kept small to restrict copper loss, winding impedance, and demagnetizing MMF of armature reaction. At the same time it is desirable that the material possess sufficient coercive force to withstand the demagnetizing MMF of a number of series turns adequate to develop the specified voltage with a quantity of flux small enough to permit the use of a modest amount of steel for the magnetic path. In addition, the magnets' residual flux must be held to a level such that the required keeper size is consistent with machine dimensions (e.g., end extension and housing I.D.'s, rotor O.D, etc.). The material's recoil permeability (ratio of Flux Density, B, to Coervice Force, H, for small values of H) should be small in order to minimize regulation of terminal voltage with load and temperature.

In general, materials possessing high residual flux exhibit low coercive force and vice versa. Recoil permeability is essentially proportional to coercive force although several of the highly oriented materials such as Alnico 5 DG and Alnico 5-7 enjoy a recoil permeability disproportionate to their coercive forces. The ultimate combination of high coercive force and low recoil permeability is displayed by many of the ceramic magnet materials but in general their residual fluxes are low and their magnetic properties are highly temperature dependent.

During early design effort on the inverter generator, Alnico 8 proved to possess the combination of residual flux, coercive force, and recoil permeability conducive to the best combination of machine size and performance attainable within the scope of the specification. At that time an improved material, Alnico 9, was put on the market which allegedly combined the high coercive force and low recoil permeability of Alnico 8 with a residual flux level approximately 20 percent higher. Designs based on this material proved superior to the Alnico 8 versions and Alnico 9 was specified for the inverter generator.

B. Alnico 9 Production Problems

Magnet specifications for the Alnico 9 were set up on the basis of the supplier's "guaranteed" minimum B-H curve and magnet blocks 2.000 x 2.000 x 1.250 inches with grain orientation along the 1.250 inch dimension.

Generator performance calculations indicated that a design using such magnets would satisfactorily comply with the inverter specification. The magnet dimensions were subsequently changed to 2.000 x 1.000 x 1.250 inches on the recommendation of the supplier since he predicted that this configuration would produce sounder castings.

During the course of magnet production, it was found that the magnet material could not be brought up to the specified flux level although the grain orientation appeared satisfactory from a metallurgical standpoint. After numerous unsuccessful attempts to produce acceptable magnets, the supplier, with the approval of Westinghouse and AGC, shipped magnets possessing residual fluxes ranging from 102 percent to 95 percent of the specified value. Supplier's tests indicated that all the magnets met the coercive force requirement.

C. Effect of Decreased Magnet Flux Density on Inverter Performance

As soon as the residual flux values of the magnets actually available were known, the inverter performance was reanalyzed based on the following parameters:

1. A magnet B-H curve derived from the supplier's minimum "guaranteed" curve by scaling down the flux density values by the ratio of test residual flux to published residual flux.
2. The calculated generator saturation curve.
3. The calculated magnet leakage flux.
4. Calculated generator winding parameters.
5. Specification values of load, voltage, power factor, temperature and frequency.

It was determined that by using a lower value of PU stabilization than that specified, rated voltage could be produced at rated load, power factor, and frequency. This analysis is covered more fully in another section of this report (Generator Overload Capabilities) and the report "Analysis of Low Magnet Flux Density on SNAP-8 Inverter Alternator Performance," L. C. Carter and E. S. Ortoli, Westinghouse Electric Corporation, December 17, 1964.

Tests on the completed inverter indicated that the actual flux leakage was significantly greater than calculated leakage. To compensate for the resultant reduction in flux available for voltage generation in order to maintain the 220 CPS load voltage at its specified value, it was necessary to further reduce the PU value of load stabilization to approximately 1 PU based on rated current and power factor for 220 CPS operation. In addition, since the effect of increased leakage is much more pronounced at the 220 CPS operating condition, adjustment of stabilization to produce rated voltage at 220 CPS results in a larger than rated voltage at the 95-CPS operating condition.

III. GENERATOR OVERLOAD CAPABILITIES

A. Specification and Design Overload Point

The inverter specification calls for 3 per unit (PU) load stabilization of the rotor magnets. Based on the maximum rated current, minimum rated power factor, and the design parameters of the machine, operation at this point imposes a demagnetizing magnetomotive force of 2328 Amp - Turns/Pole on the magnets. Calculations using the "guaranteed" minimum B-H curve for the magnets indicated that the rotor magnets, once stabilized, could be operated up to 3 PU at 40°C with no permanent reduction in terminal voltage. The corresponding overload point at 205°C was 2.6 PU based on a 5 percent magnet flux reduction and decreased electrical steel permeability at the higher temperature.

Because of manufacturing problems, the magnet supplier was unable to provide magnets meeting his originally "guaranteed" minimum B-H curve. The magnets actually supplied and used exhibited values of flux density ranging from 102 percent to 95 percent of those published. Magnets were paired at each pole to minimize the variation in flux densities.

Calculations based on B-H curves with 98 percent of the published flux density values (corresponding to the average flux density per pole) and 95 percent of the published flux density values (corresponding to that of the poorest magnet used) indicated the following PU stabilizations.

% of Specified Flux	PU Stabilization	
Density	40°C	205°C
100	3.00	2.60
98	2.77	2.26
95	2.40	1.32

B. Overload Stabilization Based on Test Data

Measurements of residual flux per pole during magnetization of rotors S/N 1 and S/N 2 indicated that the rotor magnets were producing 95 percent or more of specified flux density. The generator should thus have possessed 2.40 PU load stabilization as shown above.

Rotor S/N 1 was initially load stabilized to produce maximum rated voltage at rated load, 2850 RPM operation. Test data showed that the rotor magnets were stabilized in excess of 2.13 PU. A check of terminal voltage at rated load, 6600 RPM operation indicated that the voltage was less than the minimum rated value (86.6 volts line-line) by approximately 3 volts during operation in air at sea level.

Based on the computed magnet curve, leakage flux line, and generator saturation curves, it appeared it would be possible to stabilize the magnets to produce rated voltage (88 volts line-line) at rated load, 6600 RPM. The PU value of load stabilization would thereby be reduced and the 95 CPS load voltage increased.

The rotor was remagnetized and reassembled into the inverter without load stabilizing the magnets. Voltage during operation at full load, 6600 RPM was slightly below the minimum limit (85.6 vs 86.6 volts line-line). Heating and possible overloading during the 5 hour 8.5 minute voltage and frequency stability test (inverter housing insulated and pressurized with helium) reduced the voltage to 83.0 volts.

During the remagnetization of the rotor, leakage fluxes from pole end to pole end and from tip to pole tip were measured. Comparison of measured values of leakage flux with calculated values indicated that the test values were significantly larger. The effect of this discrepancy is, of course, to decrease the amount of useful flux and hence generated voltage at any given combination of load and power factor.

Rotor S/N 2 was magnetized and operated at full load, 6600 RPM, without prior load stabilization. Terminal voltage was slightly in excess of the rated value (88.9 versus 88.0 volts line-line) but within the specification limit (89.8 volts).

Based on extrapolation from test data (refer to Section on Generator Rotor Leakage Flux), it appears inverter S/N 1 is stabilized to 0.99 PU and inverter S/N 2 is stabilized to 1.00 PU based on maximum rated current and minimum rated power factor (39.7 amps and 0.28 lagging power factor). These PU values represent the levels of stabilization attained by loading with rated current and power at 220 CPS. Since the inverter voltage was at or below its rated value, no additional loading was imposed. Further testing may indicate somewhat higher PU loads can be carried without significant permanent reduction in terminal voltage. (Aerojet-General Corporation test data of voltage regulation versus load indicated such a condition on inverter S/N 1.)

IV. GENERATOR ROTOR LEAKAGE FLUX

A. Design Factors Affecting Inverter Output Voltage

For a specified set of operating conditions, the inverter output voltage is determined by generator stator winding parameters, magnet properties, and rotor configuration. The generator is designed with a small air gap and low iron saturation so essentially all the demagnetizing amp-turns impressed on the rotor magnets are determined by the winding configuration (e.g., pitch, distribution, turns/phase) and load. The flux density and coercive force (in conjunction with the magnet dimensions) define the demagnetization curve of the magnet while the recoil permeability fixes the slope of the minor hysteresis loop. The flux density, coercive force, and recoil permeability are characteristic properties of the magnet material. The demagnetization curve and minor hysteresis loop, when combined to produce the desired per unit load stabilization, determine the total flux available from the magnets for any given value of demagnetizing magnetomotive force. The flux available for voltage generation at any operating point is the difference between the total flux produced by the magnet and the leakage flux at that point.

B. Calculated Design

The inverter generator was designed by combining magnet size and properties and winding parameters such that total flux, leakage flux, and winding voltage drops at the two specified operating points produced the correct terminal voltage. A tapped winding was used with conductor size and winding configuration chosen to produce low winding impedance and demagnetizing armature reaction amp-turns at the 95 CPS operating condition and higher impedance and demagnetizing amp-turns but also correspondingly higher generated voltage at the 220 CPS operating condition.

The flux path seen by the magnets consists not only of the generator stator but also structural material in the vicinity of the magnets and air paths surrounding the rotor. Since flux traversing the latter two paths does not contribute to voltage generation but must nevertheless be provided by the field magnets, it represents a portion of magnet capacity which must be built into the machine but which does not contribute to useful output. Hence every effort is made to minimize this so-called "in stator" leakage.

The inverter is designed such that ferromagnetic material does not exist sufficiently near the magnets to produce significant leakage paths. Thus, most of the leakage flux follows constant permeance air paths between magnet sides and magnet ends and is a linear function of the magnetic potential existing between various elements of the magnetic circuit.

C. Test Results

No-load tests on inverter S/N 1 indicated that test voltage and calculated voltage were in agreement. The unit was stabilized to produce maximum rated voltage at full load, 95 CPS operation. When the unit was subsequently operated at full load, 220 CPS, the terminal voltage was found to be below the minimum rated voltage. During a subsequent disassembly of the inverter, measurements were made of the various components of leakage flux (except for that between the pole sides which was inaccessible because of the aluminum damping circuit).

Test values of leakage exceeded calculated values except in the case of end leakage. The discrepancy between test and calculated values appeared to be particularly significant in the case of side leakage. (Since the test value of this quantity could not be measured directly but was determined indirectly from the various measured quantities, it included measurement errors in these values as well as in its own value.) Total test leakage flux was approximately 165 percent of calculated leakage.

D. Effect of Increased Flux Leakage on Inverter Performance

The excess of actual leakage over predicted leakage resulted in two undesirable effects on inverter performance - specified 95 CPS and 220 CPS voltages could not be met with a single level of magnet stabilization and the per unit value of load stabilization attainable while meeting either the 95 CPS or 220 CPS rated voltage was significantly less than the specified value.

One consequence of the high test leakage is an increase in the slope of the leakage line over the calculated value. Thus the rate of decrease of useful flux with an increase of demagnetizing armature reaction amp-turns is raised. This condition makes it impossible to produce both low and high speed rated load voltages at a single level of magnet stabilization since the relation between the useful fluxes at low speed and at high speed rated loads is different than that on which winding and magnet design was based. If the magnets are stabilized to produce rated load volts at 95 CPS, the 220 CPS load voltage is low and if stabilization to produce rated load voltage at 220 CPS is effected, the 95 CPS load voltage is high.

In addition, the discrepancy between test and calculated leakage values increases linearly with an increase in demagnetizing amp-turns. This point is illustrated by the fact that the test and the calculated curves of useful flux versus demagnetizing amp-turns are reasonably close in the vicinity of the 95 CPS full load point (291 amp-turns) but diverge at the 220 CPS full load point (776 amp-turns). (Figure 2)

The discrepancy between test and calculated leakage is brought about by three factors - inaccuracies in the leakage permeance formulas arising from assumptions and approximations used in their derivations, unaccounted leakage existing between the two magnet segments in each pole, stray leakage paths in the machine.

Test data is used to determine the pertinent operating curves for inverters S/N 1 and S/N 2. Test and calculated operating curves and compared in Figures 3 and 4. (Note that the "test" curves represent a composite of various pieces of data and thus do not completely agree with test readings at each and every point.)

Calculations from test data indicate that the effective flux density of the magnets of rotor S/N 1 is 95 percent of the specified value while that of rotor S/N 2 is 98 percent of the specified value. Based on values of residual flux supplied by the magnet manufacturer the difference in magnetic strength between rotors S/N 1 and S/N 2 would not be expected to be this large. Magnetic leakage paths, stators, and magnetizing equipment and techniques for the two inverters were nearly identical so it would appear that the difference in effective flux density arises from differences in the rotors themselves. There are three possible contributing factors. One is manufacturing variations (e.g., fits, heat treating, etc.) which would affect the ability of the rotor magnets to reach a fully saturated condition. (Note that both rotors were checked for flux per pole during magnetization and in all cases met or exceeded the value corresponding to 95 percent of specified value.) The second factor is variation in the shape of the actual magnet curve relative to the specified curve. Figures 5 and 6 qualitatively illustrate both conditions. Finally, if the magnets of rotors S/N 1 and S/N 2 correspond to the 98 percent of specified flux density B-H curve and were fully saturated but the PU stabilization of S/N 1 exceeded that of S/N 2 an apparent difference in flux density similar to that noted would result. (Aerojet-General Corporation voltage regulation test data indicates such a condition may exist.)

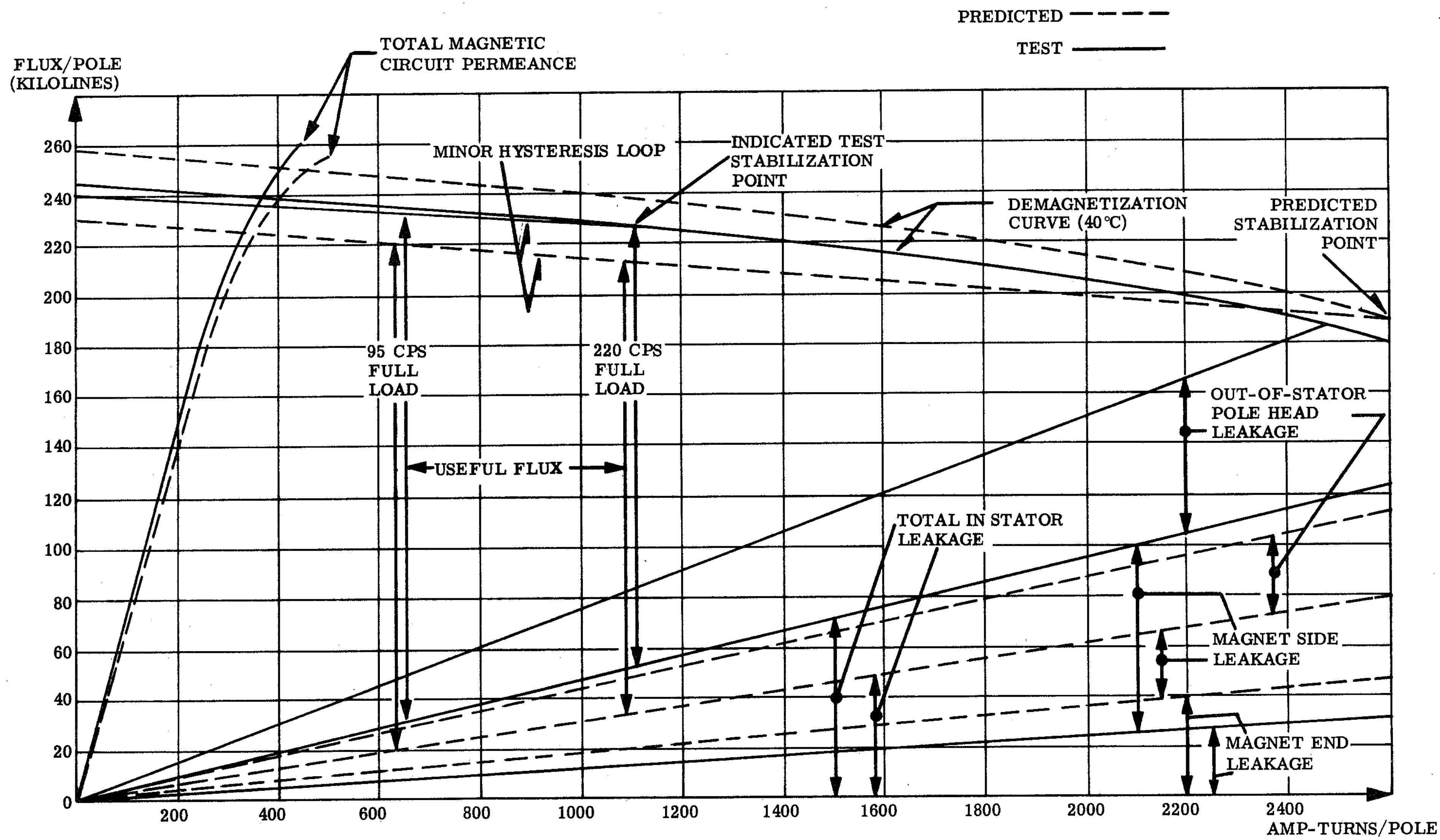

Figure 3. Test and Predicted Operating Curves
Inverter S/N 1

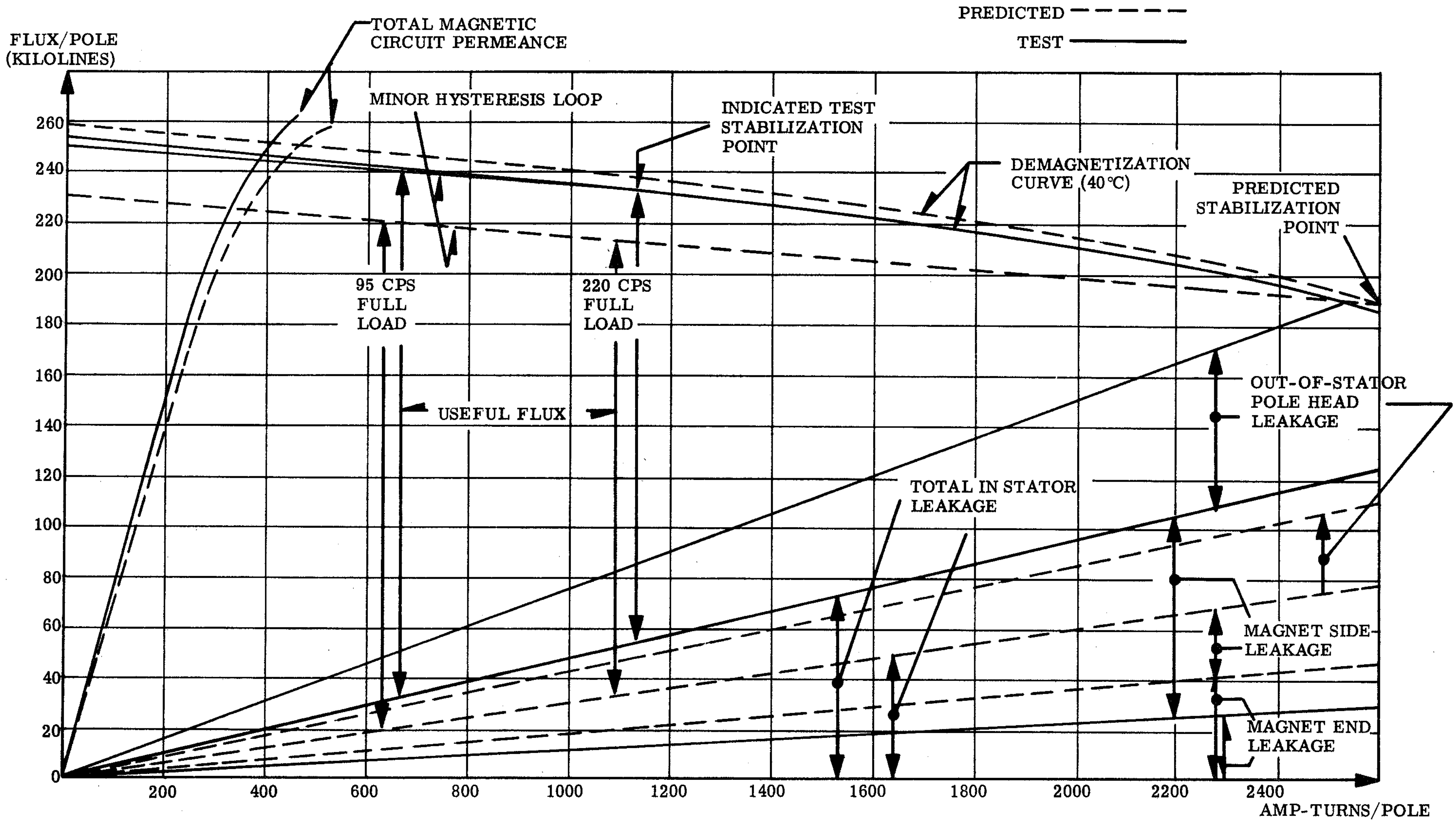

Figure 4. Test and Predicted Operating Curves
Inverter S/N 2

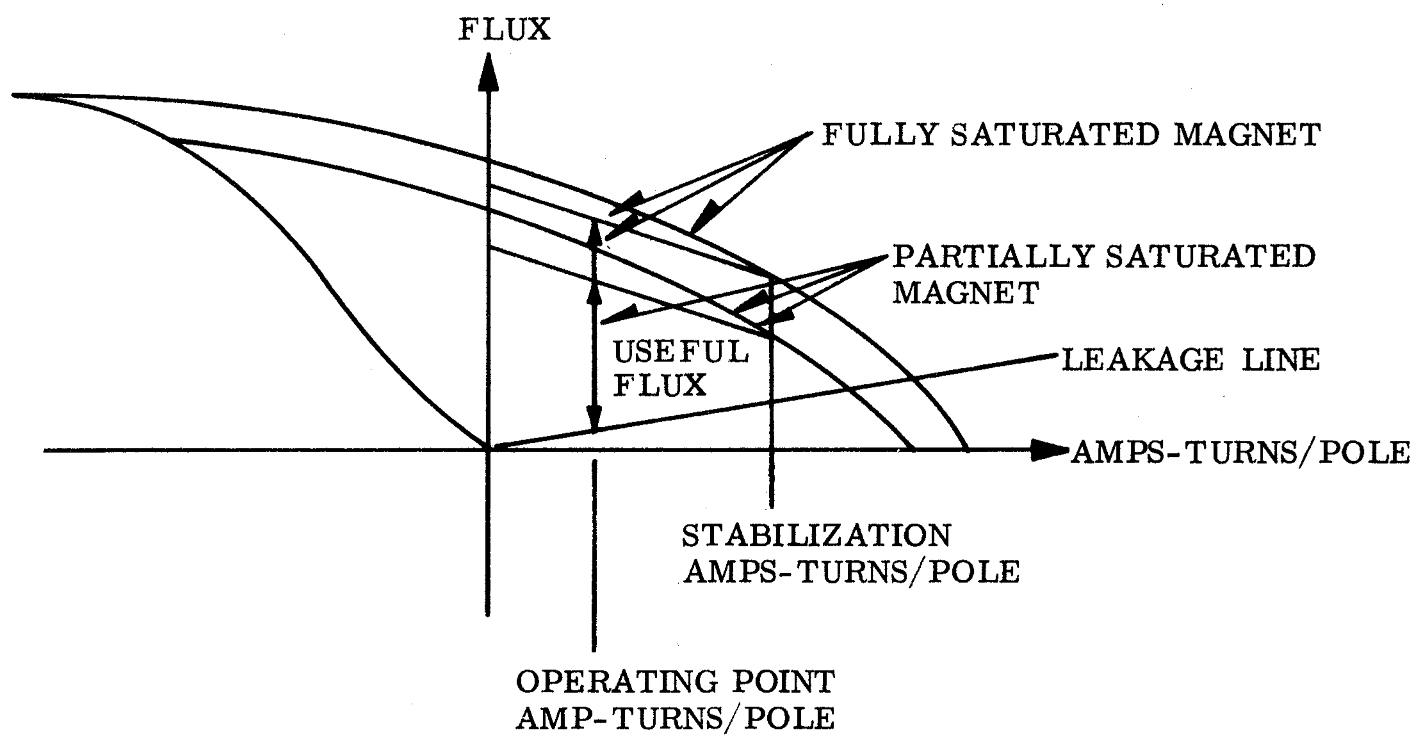

Figure 5. Demagnetization Curves and Minor Hysteresis Loops for Fully and Partially Saturated Magnets

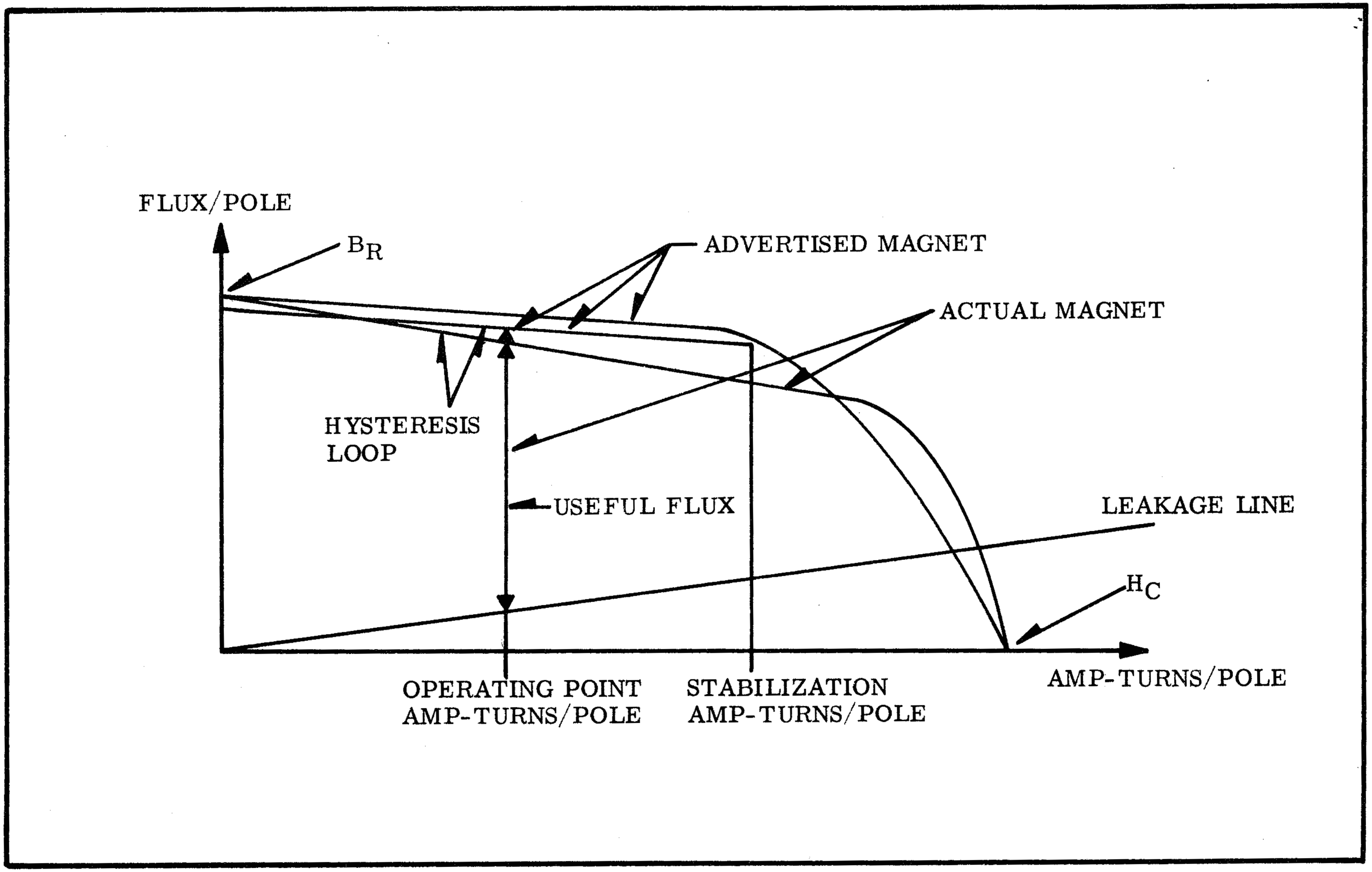

Figure 6. Demagnetization Curves and Minor Hysteresis Loops for Magnets With Same BR and HC But Different Useful Flux

SECTION III

SUGGESTED AREAS FOR FUTURE DEVELOPMENT

The manufacture and testing of the two inverters revealed several areas which should be developed further in order to provide a unit which meets all the requirements of the ultimate space application. Some of the most important are:

1. Generator Stator Winding

The original windings had to be stripped and rewound before they would pass dielectric test. Changes in winding techniques and winding design should be developed to improve windability.

2. Weight

The total weight of the inverter was increased almost 2 to 1 by a housing and heat sink redesign which was directed by Aerojet to minimize welding and sealing problems on the first two units. These should be redesigned to be compatible with space weight standards.

3. Terminals and Thermocouple Headers

Presently available ceramic seal terminals and thermocouple headers leave much to be desired. A search should be made for better terminals and headers.

4. Welded Joints

Experience on the first two units disclosed a need for further development of weld joints and weld techniques. Terminal and thermocouple header weld joints definitely need to be changed.

5. Environmental Testing

The first two units were not subjected to environmental tests. These will be required on the final configuration.

6. Radio Noise Filtering

The first two units did not have radio noise filters because filters developed for the first configuration would not be suitable for the ultimate configuration.

7. Permanent-Magnet Materials

The Alnico IX magnets did not meet the published curve of magnet properties. The available properties will have to be defined before proceeding with any redesign.

8. Inverter Overload Capabilities

The present inverter does not meet the 3 per unit overload required by the AGC Specification because the magnets did not meet the published property curve. This must be considered in any redesign.

9. Efficiency at 6600 RPM

The present inverter does not meet the 60 percent efficiency requirement for the 6600 RPM full load operation. Various trade-offs must be evaluated to provide the best system performance.

10. Speed and Voltage Spreads

The present inverter does not meet the 5 percent limit of the AGC Specification. There is no simple cure for this situation without adding an excessive amount of weight so various trade-offs should be evaluated against the system requirements.

11. Critical Speed

The present critical speed of 9300 RPM is below the required 9900 RPM. Any reduction in section thickness of the housing will make it even more difficult to meet the critical speed requirement. The present critical speed is not detrimental for rated speed operation.

12. Generator Leakage Flux

As a result of the actual leakage flux being greater than the calculated value, it was not possible to meet both the $19 \pm 2\%$ low speed voltage and the $88 \pm 2\%$ high speed voltage. As a result, the rotors were used without stabilization in order to maintain the high speed voltage as high as possible. Various design trade-offs should be reviewed to determine what system performance is required.

13. Reactor System Requirements

The system requirements are expected to change as the reactor system is tested and developed. Heat sink requirements may increase or may be eliminated. There has even been some talk of one-speed operation. These changes will affect the ultimate inverter requirements.

14. Heat Sinks

The present heat sinks were not designed for minimum weight. A more sophisticated design such as one utilizing the heat of fusion of paraffin could be used to reduce heat sink weight.

15. Magnet Stabilization

The magnets of the first two units were not subjected to the load stabilization operation because it was decided to maintain the output voltage as high as possible during the high speed operation. It will be necessary to include this operation on any new design inverters. The final design and stabilization techniques should be reviewed to determine whether the inverter can be stabilized without an external driving means.

16. Welded Versus Brazed Electrical Connections

The AGC Specification requires "Electrical Connections between components shall be accomplished by welding."

The word "components" was interpreted by Westinghouse to mean major parts such as the generator stator and the motor stator, and certain connections inside these parts were made by brazing. Aerojet apparently meant this to mean all connections shall be welded.

It will be necessary to increase the size and weight of the inverter if welding is required on all electrical connections as the present design is not suitable for welding. Connections to the commutator should remain brazed in order to utilize developed techniques for making commutators.

SECTION IV

APPENDIX

TEST RECORD SHEETS

Test Record Sheet		
K1932888 thru 1932891	Acceptance Tests	Serial No. 1
K1935372 thru 1935375	Acceptance Tests	Serial No. 2
K1932869	Critical Speed	
K1932879 and K1932880	Speed-Adjustment	
K1932877 and K1932878	Voltage & Frequency Stability	
K1932862	Motor Saturation Curve	
K1932863 and K1932864	Generator Minor Hysteresis Loop	

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K1932888

SUBJECT: SNAP-8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP. P/N 976J412-1 SERIAL NO. 1

S. O. OR TEST NO. F4-435C D. OR L. SPEC. NO. C2F-5J SHAFT NO. CYP 19012 FRAME NO.

TO DETERMINE: DEVELOPMENT & ACCEPTANCE TESTING

PER T.S. 674141 PART 3

CONTINUITY CHECK:

T12-T22 T22-T32 T32-T12 OK

A1, F1, A2F2 OK

PHASE SEQUENCE: T11-T21-T31

TEST	% LOAD	95 CPS TERMINALS		VOLTS	220 CPS TERMINALS		VOLTS
NO 1	0	T11-T21	=	23.5	T12-T22	=	137.1
		T21-T31	=	23.45	T22-T32	=	137.1
		T31-T11	=	23.5	T32 T12	=	137.1

TEST NO 3 INSULATION RESISTANCE & TEMPERATURES

T12-GND	=	7000 MEGOHMS	A	215 °F
A2F2-GND	=	6500 MEGOHMS	B	215.5 °F
T12-A2F2	=	100000 MEGOHMS	C	216.5 °F
			D	231 °F
			E	236.5 °F
			F	232 °F

RESISTANCE

5E1 - 5E2	-	.0178	-	.062	5E2 - 5E3	-	.018	- .061
5E1 - 5E3	-	.0177	-	.0618				

PREVIOUS TEST PAGE — DATE: 7-1-65 — SIGNED: HAGER/LAMAN — ENGINEER IN CHARGE: L.C. CARTER

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

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K 1932889

SUBJECT: SNAP-8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP P/N 976J412-1 SERIAL NO. 1

S. O. OR TEST NO. F4-435C D. OR L. SPEC. NO. C2F-5J SHAFT NO. CYP 19012 FRAME NO.

TO DETERMINE: DEVELOPMENT & ACCEPTANCE TESTING

PER T.S 674141 PART 3

TEST NO 4 DIELECTRIC

5E1 TO GROUND OK
5E4 TO GROUND REJECT
5E1 TO 5E4 OK

5E4 TO GND 400 VOLTS FOR 1 MIN, LEAKAGE 1.65 MILAMP

COMP LEAKAGE PER ENG

5E1 TO GROUND COMP LEAKAGE
.52 MILAMP COMP J

5E1 TO 5E4 COMP LEAKAGE
1 MILAMP COMP E

T12 TO GND 925 VOLTS FOR 1 MIN OK
A2F2 TO GND 525 VOLTS ON & OFF OK

PREVIOUS TEST PAGE

DATE: 7-1-65

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ENGINEER IN CHARGE: L.C. CARTER

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932890

SUBJECT SNAP-8 ROTARY INVERTER

CUSTOMER AEROJET GENERAL CORP P/N 976J412-1 SERIAL NO. 1

S. O. OR TEST NO. F4-435C D. OR L. SPEC. NO. C2F-5J SHAFT NO. CYP 19012 FRAME NO.

TO DETERMINE DEVELOPMENT & ACCEPTANCE TESTING

PER T.S. 674141 PART 3

TEST NO 2(A)

	VOLTS	1-2	20.18	20.18	20.2	20.22	20.3	20.25	20.3	20.15	20.3	20.3	20.3	20.35
	VOLTS	2-3	20.2	20.15	20.2	20.22	20.3	20.25	20.3	20.15	20.3	20.3	20.3	20.35
	VOLTS	3-1	20.2	20.15	20.2	20.22	20.3	20.25	20.25	20.15	20.3	20.3	20.3	20.35
	A1	X 10	3.72	3.72	3.72	3.7	3.7	3.74	3.74	3.74	3.74	3.74	3.74	3.74
	A2	X 10	3.73	3.73	3.73	3.73	3.73	3.74	3.74	3.74	3.74	3.74	3.74	3.74
	A3	X 10	3.73	3.73	3.73	3.73	3.73	3.74	3.74	3.74	3.74	3.74	3.74	3.74
	TOTAL	WATTS	372.5	372.5	372.5	375	375	375	377.5	377.5	382.5	375	375	375
	AV		28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
	AA		24.4	24.4	24.4	24.4	24.4	24.4	24.2	24.2	24.2	24.2	24.2	24.2
	FV		12.16	12.15	12.25	12.3	12.35	12.85	13.3	13.75	13.9	14.0	14.05	14.1
	FA		2.13	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12
	CPS		95	95	95	95	95	95	95	95	95	95	95	95
TC	A	°F	110	121	127	132	136	158	174	191	194	198	203	206.5
	B	°F	111	121	127	132	137	158	174	190	193.5	198	202.5	206.5
	C	°F	110	121	128	132	137	158	174	191	194	198	203	206.5
	D	°F	116	122	130	136	140	161	181	199.5	203	207.5	212.5	217
	~~E~~F	°F	123	136	141	147	151	172	192	211	212	218.5	223.5	227
	~~F~~E	°F	114	124	130	135	140	161	180	198	202	206	212	215.5
	TIME	HR/MIN	/0	/15	/30	/45	1/0	2/0	3/0	4/0	4/15	4/30	4/45	5/0

CON'T ON PAGE K1932891

K1932889 PREVIOUS TEST PAGE   7-1-65 DATE   HAGER / LAMAN SIGNED   L.C. CARTER ENGINEER IN CHARGE

TEST RECORD
WESTINGHOUSE FORM 2202 E 2207

THIS SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932891

SUBJECT: SNAP-8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP P/N 976J412-1 SERIAL NO. 1

S. O. OR TEST NO. F4-435C D. OR L. SPEC. NO. C2F-5J SHAFT NO. CYP 19012 FRAME NO.

TO DETERMINE: DEVELOPMENT & ACCEPTANCE TESTING

PER T.S. 674141 PART 3

TEST NO 2(B) CON'T FROM PAGE K1932890

	VOLTS	1-2	—	83.0	83.1
	VOLTS	2-3	—	83.1	83.0
	VOLTS	3-1	—	83.1	83.0
	A1	x10	—	3.97	3.97
	A2	x10	—	3.97	3.97
	A3	x10	—	3.98	3.97
	TOTAL	WATTS	—	1750	1715
	AV		28.0	28.0	28.0
	AA		132.4	148.8	159.6
	FV		3.62	3.68	3.58
	FA		.52	.48	.43
	CPS		220	220	220
TC	A	°F	212	228	240
	B	°F	215	230	240
	C	°F	216	230	241
	D	°F	216	230	251
	~~E~~ F	°F	282	326	364
	~~F~~ E	°F	216	230	249
	TIME	HR/MIN	5/0	5/4	5/8.5
	Weight		3710		4470

PREVIOUS TEST PAGE: K1932890 DATE: 7-1-65 SIGNED: HAGER/LAMAN ENGINEER IN CHARGE: L.C. CARTER

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

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K 1935372

SUBJECT: SNAP 8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP. P/N 976J412-1 SERIAL NO. 2

S. O. OR TEST NO. E4-435-C D. OR L. SPEC. NO. C2F5J SHAFT NO. CYP19012 FRAME NO.

TO DETERMINE: DEVELOPMENT AND ACCEPTANCE TEST

PER T.S. 674141 PART 3.

CONTINUITY CHECK:

T12 - T22	T22 - T32	T32 - T12	OK
A1	F1	A2F2	OK

PHASE SEQUENCE: T11 - T21 - T31

TEST	% LOAD	95 CPS TERMINALS		VOLTS	220 CPS TERMINALS	VOLTS
NO 1	0	T11 - T21	=	24.2	T12 - T22	= 140.1
		T21 - T31	=	24.2	T22 - T32	= 140.1
		T31 - T11	=	24.2	T33 - T12	= 140.1

TEST NO 3 INSULATION RESISTANCE & TEMPERATURES.

T12 - GND = 1800 MEGOHMS	A	210	°F
A2F2 - GND = 120 MEGOHMS	B	210	°F
T12 - A2F2 = 1500 MEGOHMS	C	213	°F
	D	243	°F
	E	266	°F
	F	246	°F

PREVIOUS TEST PAGE   DATE: 9-14-65   SIGNED: Wis Lama   ENGINEER IN CHARGE: L. Carter

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

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K 1935373

SUBJECT SNAP 8 ROTARY INVERTER

CUSTOMER AEROJET GENERAL CORP. P/N 976J412-1 SERIAL NO. 2

S. O. OR TEST NO. F4-435C D. OR L. SPEC. NO. C2F5J SHAFT NO. CYP19012 FRAME NO.

TO DETERMINE DEVELOPMENT AND ACCEPTANCE TEST

PER T.S 674141 PART 3

TEST NO 4. DIELECTRIC

T12-GRND.	OK	J COMPENSATED	1 MA.
A2F2-GRND	OK	G COMPENSATED	.45 MA
T12 - A2F2	OK	G COMPENSATED	.18 MA

PREVIOUS TEST PAGE

DATE 9-14-65

SIGNED Wise - Lance

ENGINEER IN CHARGE L. Carter

WESTINGHOUSE FORM 2509 E BODY

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K1935374

SUBJECT SNAP 8 ROTARY INVERTER

CUSTOMER AEROJET GENERAL CORP. P/N976J412-1 SERIAL NO. 2

S. O. OR TEST NO. F4-435C D. OR L. SPEC. NO. C2F5J SHAFT NO. C4P19012 FRAME NO.

TO DETERMINE DEVELOPMENT AND ACCEPTANCE TESTS.

PER T.S. 674141 PART 3.

TEST NO 2(A)

VOLTS	1-2	20.85	20.85	20.85	20.85	20.85	20.85	20.85	20.85	20.85	20.85	20.85	20.85
VOLTS	2-3	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
VOLTS	3-1	20.85	20.85	20.85	20.85	20.85	20.85	20.88	20.86	20.85	20.85	20.85	20.85
A1		37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
A2		37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
A3		37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4
TOTAL WATTS		375	375	375	375	375	375	375	375	375	375	375	375
AV		28	28	28	28	28	28	28	28	28	28	28	28
AA		23.8	24.0	23.8	23.6	23.6	23.2	22.8	22.6	22.4	22.4	22.4	22.4
FV		12.45	12.45	12.8	12.7	13.1	13.6	13.75	14.35	14.6	14.7	14.8	14.8
FA		2.25	2.22	2.25	2.21	2.25	2.25	2.22	2.22	2.22	2.22	2.22	2.22
CPS		95	95	95	95	95	95	95	95	95	95	95	95
TC A	°F	102	109	116	121	126	147	166	184	188	192	197	201
B	°F	101	108	115	120	125	146	166	183	188	192	197	200
C	°F	101	109	115	121	126	147	167	184	188	192	192	201
D	°F	110	117	125	130	135	158	176	194	200	204	209	213
F	°F	122	130	135	142	146	166	186	202	206.5	210	216	219
E	°F	97	103	109	115	120	145	177	195	200	205	210	213
TIME	HR./MIN.	/0	/15	/30	/45	1/0	2/0	3/0	4/0	4/15	4/30	4/45	5/0

PREVIOUS TEST PAGE

DATE 9-14-65

SIGNED Weir - Lama

ENGINEER IN CHARGE L. Carter

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1935375

SUBJECT: SNAP 8 ROTARY INVERTER
CUSTOMER: AEROJET GENERAL CORP. P/N 996T412-1 SERIAL NO. 2
S. O. OR TEST NO. EH-435C D. OR L. SPEC. NO. CAF 5J SHAFT NO. CYP 19012 FRAME NO.
TO DETERMINE: DEVELOPMENT AND ACCEPTANCE TEST

PER TEST SPEC 674141 PART 3

TEST NO 2 (B) CONTINUED FROM K1935374

VOLTS	1-2	89.0	88.9	88.5
VOLTS	2-3	89.0	88.9	88.5
VOLTS	3-1	89.0	88.9	88.5
A1		39.7	39.7	39.7
A2		39.7	39.7	39.7
A3		39.7	39.7	39.7
TOTAL WATTS		1695	1695	1692
AV		28.0	28.0	28.0
AA		158	162	172
FV		2.3	2.2	1.8
FA		.3	.28	.2
CPS		220	220	220
TC A		205	227	236
B		205	225	234
C		208	226	239
D		210	219	242
F		267	328	370
E		212	218	242
TIME	HR/MIN	5/0	5/4	5/8.5
Watts	input	4425	4540	4820
Watts	output	1695	1695	1692
Watts	loss	2730	2845	3128
Eff		38.3	37.4	35.2

K1935374 PREVIOUS TEST PAGE — 9.14.65 DATE — Wise Sousa SIGNED — L. Carter ENGINEER IN CHARGE

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932869

SUBJECT: SNAP-8 ROTARY INVERTER
CUSTOMER: AEROJET GENERAL CORP. SERIAL NO.: UNIT #1
S. O. OR TEST NO.: F4-435B D. OR L. SPEC. NO.: C2F-5J SHAFT NO.: CYP 19012 FRAME NO.:
TO DETERMINE: CRITICAL SPEED

		x
V-12		19.2
V1-3		19.2
V2-3		19.2
A-1	X10	3.76
A-2	X10	3.78
A-3	X10	3.76
W-1	X5	24
W-2	X5	25
W-3	X5	26.5
RPM		2850
FREQ		95
PHASE		
DCV.	ARM	28
DCA	X6 ARM.	4.1
DCV.	SHUNT FLD.	13.1
A.X1	SHUNT FLD.	2.03
COMM		
TC.# OF		
D		
E		
F		
A		
B		
C.		

CRITICAL SPEED TEST STOPED AT 310 CYCLES DO TO UNUSAL NOISE AND BUSSING SOUND

AFTER CRITICAL SPEED TEST.

K 1932868 — PREVIOUS TEST PAGE
5-5-65 — DATE
N. WISE - GS. KL. BS — SIGNED
E. ORTOLI — ENGINEER IN CHARGE

TEST RECORD
WESTINGH E FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932879

SUBJECT: SNAP 8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP. SERIAL NO.: UNIT #1

S. O. OR TEST NO.: F4-435C D. OR L. SPEC. NO.: SHAFT NO.: E2F-5J-CYP19012 FRAME NO.:

TO DETERMINE: DEVELOPMENT & ACCEPTANCE TESTING

PARA 6. SPEED ADJUSTMENT AND TEST PER TS#674141 PART 3.5 TEST #2.

V1-2		20.1	17.9	22.2	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
V1-3		20.1	17.8	22.2	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
V2-3		20.1	17.8	22.2	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
A1	X10	3.74	3.71	3.76	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
A2	X10	3.74	3.71	3.76	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74	3.74
A3	X10	3.74	3.71	3.76	3.74	[illegible]	3.74	3.74	3.74	3.74	3.74	3.74	3.74
W1	X5	25.0	22.0	27.5	25.0	[illegible]	25.0	[illegible]	25.0	25.0	25.0	25.0	25.0
W2	X5	26.0	23.5	29.0	27.0	[illegible]	25.0	[illegible]	25.0	25.0	25.0	25.0	25.0
W3	X5	24.0	22.0	27.0	24.5	24.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
ARM VOLTS		28	28	28	28	28	28	28	28	28	28	28	28
ARM AMPS		23.6	20.8	20.64	23.6	21.4	23.0	23.0	23.0	23.0	23.0	23.0	23.0
FLD AMPS		2.0	3.15	1.38	1.98	1.97	2.0	1.99	2.02	2.05	2.02	2.03	2.02
FLD VOLTS		10.89	19.2	7.6	10.95	11.08	11.4	11.37	11.8	11.95	11.85	11.85	11.85
RPM		2850	2550	3150	2850	2850	2850	2850	2850	2850	2850	2850	2850
FREQ		95	85	105	95	95	95	95	95	95	95	95	95
COMM		1	1	1	1	1	1	1	1	1	1	1	1
TC	°F												
A					100	106	110	[illegible]	125	130	131	130	130
B					98	104	109	[illegible]	124	129	130	130	130
C					98	104	110	[illegible]	124	128	130	130	130
D					112	120	126	[illegible]	136	140	140	139	138
E					110	118	[illegible]	[illegible]	135	139	138	137	136
F					150	154	155	[illegible]	162	166	161	159	150
TIME MIN		3	4	6	15	30	45	60	120	180	240	255	270

PREVIOUS TEST PAGE

DATE: MAY 27, 1965

SIGNED: G. SCHARDT & R. LAKUE, W. MILLER & R. RIDENOUR

ENGINEER IN CHARGE: LEE CARTER

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932880

SUBJECT Snap 8 Rotary Inverter

CUSTOMER Aerojet General Corp. SERIAL NO. Unit #1

S. O. OR TEST NO. F4-435C D. OR L. SPEC. NO. SHAFT NO. E2F-5J-CYP19012 FRAME NO.

TO DETERMINE Development & Acceptance Testing

Para. 6 Speed Adjustment And Test Per. TS#674141 Part 3.5 Test #2

V1-2		20.1	20.1		Connected High Phase Terminals	85.2	85.0	77.1	91.8	84.5
V1-3		20.1	20.1			85.2	85.0	77.1	91.7	84.6
V2-3		20.1	20.1			85.4	85.0	77.1	91.5	84.5
A1	X10	3.74	3.74			3.97	3.97	3.94	3.98	3.96
A2	X10	3.74	3.74			3.97	3.97	3.94	3.98	3.96
A3	X10	3.74	3.74			3.97	3.97	3.95	3.99	3.96
W1	X5	25.0	25.0			115.0	115.0	99.0	130.0	114.0
W2	X5	25.0	25.0			115.0	115.5	99.5	131.0	115.0
W3	X5	25.0	25.0			115.0	114.5	99.0	129.5	114.0
Arm Volts		28	28			28	28	28	28	28
Arm Amps		23.0	23.0			144	149	121	173	157
Fld Amps		2.02	2.02			.4	.4	.6	.1	.39
Fld Volts		11.88	11.8			2.35	2.5	3.8	.8	2.55
RPM		2850	2850			6600	6600	6000	7200	6600
Freq		95	95			220	220	200	240	220
Smm		1	1			1	1	1	1	1
T°	°F									
A		130	130			155	177	186	192	200
B		130	130			154	173	179	187	193
C		129	129			154	172	178	184	190
D		138	137			144	171	185	196	206
E		136	136			143	169	182	192	202
F		158	157			276	324	322	390	392
Time Min		285	300			300	304	306	307.5	308.5
Watts input						4030				4390

K1932879 PREVIOUS TEST PAGE

May 27, 1965 DATE

G. Schaadt & R. LaCue, W. Miller & R. Ridenour SIGNED

Lee Carter ENGINEER IN CHARGE

TEST RE RD
WESTINGH SE 4 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932877

SUBJECT SNAP-8 ROTARY INVERTER

CUSTOMER AEROJET GENERAL CORP   SERIAL NO. UNIT #1

S. O. OR TEST NO. F4-435C   D. OR L. SPEC. NO. E2F-3J-   SHAFT NO. CYP 19012   FRAME NO.

TO DETERMINE DEVELOPMENT & ACCEPTANCE TESTING

VOLTAGE AND FREQ STABILITY.

V1-2		20.2	23.75	23.75	23.35	23.4	23.5	23.0	23.0	20.25	20.25	20.25	20.25
V1-3		20.3	23.75	23.75	23.35	23.4	23.5	23.0	23.0	20.25	20.2	20.2	20.2
V2-3		20.2	23.75	23.75	23.35	23.35	23.5	23.0	23.0	20.25	20.2	20.2	20.25
AMPS 1	X10	3.74	3.76	3.76	3.76	3.76	3.76	3.76	3.76	3.74	3.74	3.74	3.74
AMPS 2	X10	3.74	3.76	3.76	3.76	3.76	3.76	3.76	3.76	3.74	3.74	3.74	3.74
AMPS 3	X10	3.74	3.76	3.76	3.76	3.76	3.76	3.76	3.76	3.73	3.73	3.73	3.73
WATTS 1	X5	26	30	30	30	30	30	30	30	26	26	26	26
WATTS 2	X5	25	31	31	31	31	31	31	31	25.5	26	26	25.5
WATTS 3	X5	25	30	29.5	29.5	29.5	29.5	29.5	29.5	24.0	25	25	25.0
ARM VOLTS		28	33.0	33.0	33.0	33.0	33.0	33.0	33.0	28.0	28.0	28.0	28.0
ARM AMPS	X2	11.9	11.9	12.0	11.9	11.9	11.8	11.7	11.8	11.2	11.2	11.2	11.2
FLD AMPS		2.0	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.12	2.12	2.1	2.08
FLD VOLTS		12.0	13.41	13.4	13.41	13.6	13.55	13.68	13.7	12.61	12.68	12.48	12.4
RPM													
FREQ		95	111	110	110	110	110	110	110	95	95	95	95
COMM		1	1	1	1	1	1	1	1	1	1	1	1
T.C. °F													
A		115	120	124	125	126	128	130	130	131	133	138	141
B		115	119	123	124	126	127	129	130	130	132.5	138	140
C		115	119	123	124	126	127	128	130	130	132	137	140
D		126	134	138	140	142	144	145	146	146	147	150	153
E		125	133	136	138	140	142	142	145	145	146	150	151
F		153	158	162	163	164	166	167	168	166	168	170	173
TIME MIN			0	5	10	15	20	25	30	45	60	120	180

5-26-65   Baxter - Maxwell   Lee Carter

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932878

SUBJECT: SNAP 8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP — SERIAL NO.: UNIT #1

S. O. OR TEST NO.: E4-435 C — D. OR L. SPEC. NO.: E2F-5J- — SHAFT NO.: CYP 19012 — FRAME NO.:

TO DETERMINE: DEVELOPMENT & ACCEPTANCE TESTING

CONT FROM PAGE K1932877

VOLTAGE AND FREQ STABILITY

V1-2		20.2	20.2		85.0	84.8	84.9	80.4	80.0		84.5	
V1-3		20.2	20.25		85.0	84.8	84.9	80.1	80.0		84.3	
V2-3		20.2	20.2		85.5	84.9	84.9	80.0	80.0		84.3	
A 1	X10	3.74	3.74		3.97	3.96	3.96	3.94	3.94		3.95	
A 2	X10	3.74	3.74		3.97	3.96	3.96	3.94	3.94		3.95	
A 3	X10	3.73	3.73		3.96	3.96	3.96	3.94	3.94		3.95	
W 1	X5	26	26		116	114	115	104	105		114	
W 2	X5	26	26		112	111	111	101	102		111	
W 3	X5	25	25.5		111	110	110	100	101		110	
ARM VOLTS		28.0	28.0		28.0	28.0	28.0	27.0	27.0		28.0	
ARM AMPS	X2	11.2	11.1		69.3	69.8	73.9	70.2	70.9		76.5	
FLD AMPS		2.02	2.0		.4	.4	.4	.38	.38		.31	
FLD VOLTS		12.13	12.1		2.5	2.5	2.45	2.48	2.48		2.11	
RPM												
FREQ		95	95		220	220	220	207	207		220	
COMM		1	1		1	1		1			1	
T.C.	°F											
A		44	144		178	188	200	210	220		226	
B		43	144		174	184	195	204	210		216	
C		143	143		174	184	194	200	208		212	
D		155	154		164	177	199	216	233		240	
E		154	154		160	174	190	210	226		230	
F		180	176		278	322	378	388	392		406	
TIME MIN.		240	300		0	2.5	5.0	7.5	10.0		Rated Load and FREQ. AFTER	10 MIN. RUN.

PREVIOUS TEST PAGE: — DATE: 5-26-65 — SIGNED: Baxter-Maxwell — ENGINEER IN CHARGE: Lee Carter

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K 1932862

SUBJECT: SNAP-8 ROTARY INVERTER
CUSTOMER: AEROJET GENERAL CORP — SERIAL NO. UNIT #1
S. O. OR TEST NO. TLF4-4386 — D. OR L. SPEC. NO. E2F-5J- — SHAFT NO. CVP 19012 — FRAME NO.
TO DETERMINE: MOTOR SATURATION CURVE — SECTION II PARA #3

UNIT DRIVEN BY 50HP DYNA

RPM H&D SR# 1193	SFA W SR# 1975453	AV W SR# 2530370
3001	.2	4.14
3000	.4	8.38
	.6	12.82
	.8	16.98
	1.0	20.84
	1.2	22.98
	1.4	24.68
	1.6	25.86
	1.8	26.92
	2.0	27.76
3000	2.2	28.44
3001	2.4	29.06
3000	2.6	29.64
	2.8	30.08
	3.0	30.48
	3.2	30.92
	3.5	31.48
3000	4.0	32.32

K1932861 — PREVIOUS TEST PAGE
4-30-65 — DATE
BAXTER-HAMILTON — SIGNED
L L CARTER — ENGINEER IN CHARGE

TEST RECORD
WESTINGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K1932863

SUBJECT: SNAP-8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP. SERIAL NO.: UNIT #1

S. O. OR TEST NO.: F4-435B D. OR L. SPEC. NO.: E2F-5J- SHAFT NO.: CYP 19012 FRAME NO.:

TO DETERMINE: GENERATOR MINOR HYSTERESIS LOOP

		HIGH PHASE	LOW PHASE	HIGH PHASE	LOW PHASE		LOW PHASE	LOW PHASE	LOW PHASE	LOW PHASE	LOW PHASE	LOW PHASE
V1-2		132.8	53.2	83.2	22.6		22.4	22.2	21.75	21.7	21.6	21.7
V1-3		133.0	53.2	83.6	22.6		22.4	22.1	21.8	21.7	21.5	21.7
V2-3		132.9	53.2	83.6	22.6		22.4	22.1	21.8	21.7	21.5	21.7
A-1	X20	0	0	1.9	0	X10	.95	1.0	1.0	1.0	.95	1.0
A-2	X20	0	0	1.91	0	X10	.95	1.0	1.02	1.04	1.02	1.0
A-3	X20	0	0	1.87	0	X10	1.02	1.03	1.03	1.05	1.05	1.02
W-1	X10	0	0	54	0	X5	24.5	20.5	15	10.5	5	2.5
W-2	X10	0	0	58	0	X5	24.5	21.0	16	12	7	3.0
W-3	X10	0	0	57	0	X5	26.5	23.0	16.5	11.5	5.5	3.0
RPM		6600	6600	6600	2850		2850	2850	2850	2850	2850	2850
FREQ		220	220	220	95		95	95	95	95	95	95
DCV. ARM.		28	28	27.9	24.95		25.55	25.9	24.5	25.42	25.2	25.3
DCA. ARM.	X2	11.7	11.7	X6 22.8	X6 1.4		X6 4.2	X6 4.3	X6 3.1	X6 2.7	X6 2.1	X6 1.75
DCV.	FLD.	2.4	2.4	2.5	9.25		9.0	9.0	9.0	9.0	9.0	9.0
TC #	°F											
D				142								
E				144								
F				190								
A				154								
B				150								
C				150								

PREVIOUS TEST PAGE: K 1932862 DATE: 4-30-65 SIGNED: N. WISE - B.S. ENGINEER IN CHARGE: E. ORTOLIE

TEST RECORD
W[illegible]NGHOUSE FORM 2509 E BODY

THE SPACE ABOVE THIS LINE IS FOR FILING AND MUST NOT BE WRITTEN ON

K1932864

SUBJECT: SNAP-8 ROTARY INVERTER

CUSTOMER: AEROJET GENERAL CORP.

SERIAL NO.: UNIT # 1

S. O. OR TEST NO.: F4-435B D. OR L. SPEC. NO.: E2F-5J- SHAFT NO.: CYP 19012 FRAME NO.:

TO DETERMINE: GENERATOR MINOR HYSTERESIS

		LOW PHASE
V1-2		19.4
V1-3		19.4
V2-3		19.4
A-1	X20	1.91
A-2	X20	1.9
A-3	X20	1.85
W-1	X10	13
W-2	X10	13
W-3	X10	13.5
RPM		2850
FREQ		95
DCV.	ARM.	24.88
DCA.	ARM.	X6 4.8
DCV	FLD.	8.0
T.C.#	°F	
D		132
E		132
F		126
A		124
B		125
C		122

K1932863 PREVIOUS TEST PAGE — 4-30-65 DATE — N. WISE - BS SIGNED — E. ORTOLIE ENGINEER IN CHARGE